The Ordovician–Silurian boundary at Keisley, Cumbria

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Synopsis

At Keisley, in the Cross Fell Inlier of Cumbria, the lowest Silurian graptolite biozone recorded until recently was that of *A. atavus*, with the topmost of the underlying carbonates regarded as being of either Lower Llandovery or Hirnantian age. A temporary excavation has confirmed the Hirnantian age of the latter, and with the discovery in the overlying clastic sediments of the biozones of both *G. persculptus* and *P. acuminatus*, the Ordovician–Silurian boundary is now accurately located.

Although Upper Ordovician and Lower Silurian rocks crop out in the Cross Fell Inlier of northern England, the area is much faulted (Shotton 1935). Moreover, where reasonably continuous graptolite sequences of the Lower Silurian are exposed in Swindale Beck (Knock) and in Great Rundale Beck (Marr & Nicholson 1888: 699; Burgess & Rushton 1979: 23), the lowest biozones (below *Coronograptus cyphus*) are missing. Until recently, the earliest Silurian graptolite biozone was that recorded from the road cutting to Keisley Quarry by Marr (1906: 485) and reported by him as indicating the *Dimorphograptus confertus* Zone of Marr & Nicholson (1888). The lowest part of that zone has been shown by Rickards (1970) to equate with the *Atavograptus atavus* Biozone, and the presence of beds of this age was confirmed by Rickards from graptolite material excavated in 1965 from this locality by Temple (1968: 2).

On the Upper Ordovician side of the boundary the stratigraphical relationships and precise age of the main unit, the Keisley Limestone, have been debated for many years. The limestone has been a source of geological interest since the last century as it contains a prolific shelly fauna, is of distinctive lithology, and has a peculiar morphological form referred to as a 'knoll' by Marr (1906: 485). The views on various aspects of this mudmound have been discussed by Wright (1985); only the relationships of the carbonate mudmound to the *atavus* Biozone graptolite shales are relevant in the present context.

Marr (1906: 485) noted that the Ashgill Shales, which do occur in Swindale Beck, were not present at Keisley; and as there was insufficient room for these beds between the Silurian graptolite shales and the nearest outcrops of Keisley Limestone, he interpreted the junction as a faulted one. Burgess (1968: 343) noted that along the track leading to the quarry, the massive limestone was succeeded by calcareous mudstones and limestone nodules which were in turn overlain by the graptolite shales 'in apparently conformable sequence', and the presence of this apparently unfaulted and conformable relationship was subsequently reiterated by Burgess *et al.* (1970: 170), despite the discontinuous nature of the outcrops. An extensive brachiopod and trilobite fauna was collected by Temple (1968, 1969) from weathered limestone bands associated with unfossiliferous shales at the bend in the quarry track; this outcrop was separated by a few metres from those of both the underlying massive limestone and the overlying *atavus* Biozone shales, and the extensive fauna interpreted by Temple as being of Lower Llandovery age, a view supported by Burgess & Rushton (1979: 23) but not by Ingham & Wright (1972: 47), who regarded it as being of Hirnantian age.

The difficulty with the Keisley locality is that the beds immediately below the established *atavus* Biozone graptolite shales are concealed beneath the trackway to the quarry. To overcome this a temporary trench was dug with the aid of a mechanical digger and the complete sequence exposed (Wright 1985). Fig. 1 shows the position of the trench across the trackway and Fig. 2 the lithological log obtained.

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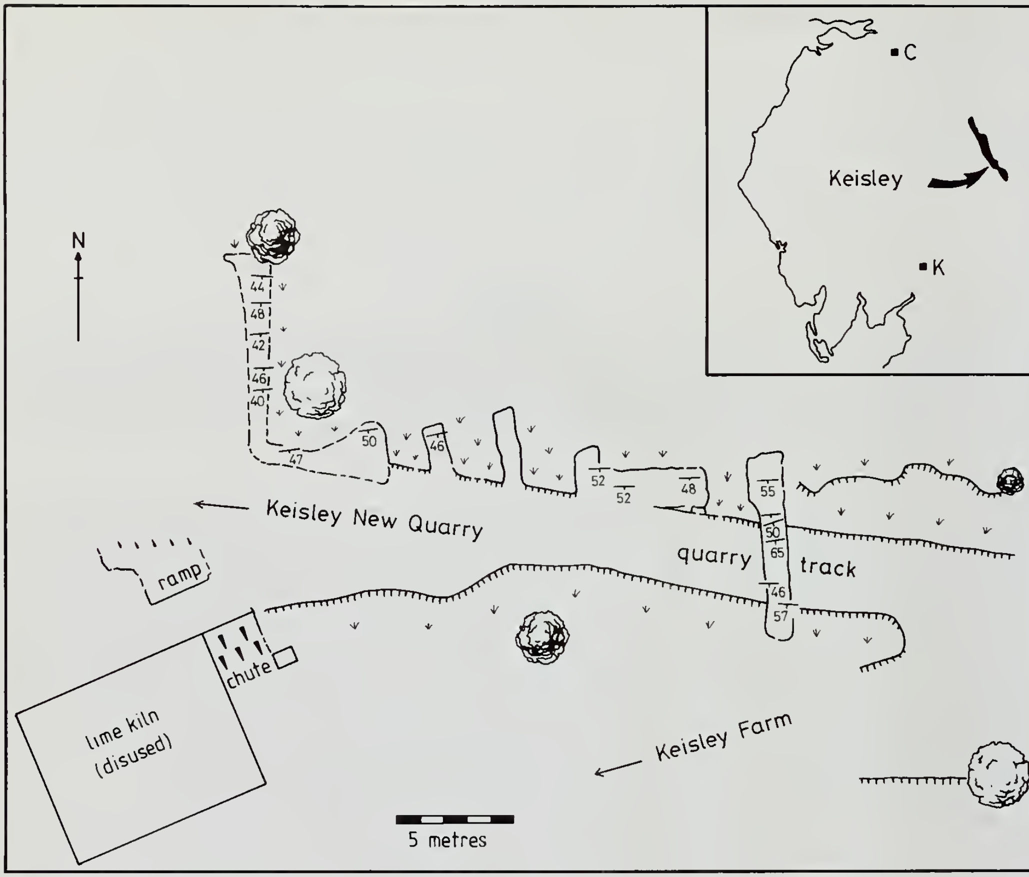

Fig. 1 Plan showing the position of the temporary trench excavated across the trackway at the eastern end of Keisley New Quarry to reveal the Ordovician–Silurian boundary (National Grid Ref. NY 7137 2379). The strikes in the trench were taken on the trench floor except for the two strikes at the southern end which are in the trench walls and thus well up in the *atavus* Biozone. Stippling in the bank to the east of the trench indicates outcrops of fossiliferous weathered limestones, the fauna of which was described by Temple (1968, 1969). Stylized trees (not to scale) represent two ash (light outlines), two sycamores (dark outlines) and a hawthorn (small figure). The inset figure shows the position of Keisley in the Cross Fell Inlier (shaded) in relation to north-west England (C—Carlisle; K—Kendal).

The lower part of the sequence up to and including unit 8 (numbering as in Wright 1985) consists of alternations of bedded limestones or calcareous nodules with calcareous siltstones. The bedded bioclastic limestones are fresh and although pelmatozoan debris, bryozoan fragments and the occasional brachiopod (including *Hirnantia sagittifera*) are to be seen on the bed surfaces, faunal lists are scant compared with those of Temple (1968) obtained from the well weathered material above the trackway. Gastropods, ostracodes and a few trilobites have been observed in thin sections of the trench limestones in which abundant *Girvanella* is probably the most revealing element palaeoenvironmentally.

The unit 7 siltstone, while by no means abundantly fossiliferous, does have a shelly fauna in the form of moulds, albeit in a broken and fragmented state. The diverse fauna includes the brachiopods *Dolerorthis praeclara*, *Hindella* sp., *Hirnantia sagittifera*, ? *Oxoplecia*, *Paracraniops* sp., *Reuschella inexpectata*, *Skenidioides scoliodus*, *Sphenotreta* sp. and *Toxorthis proteus*

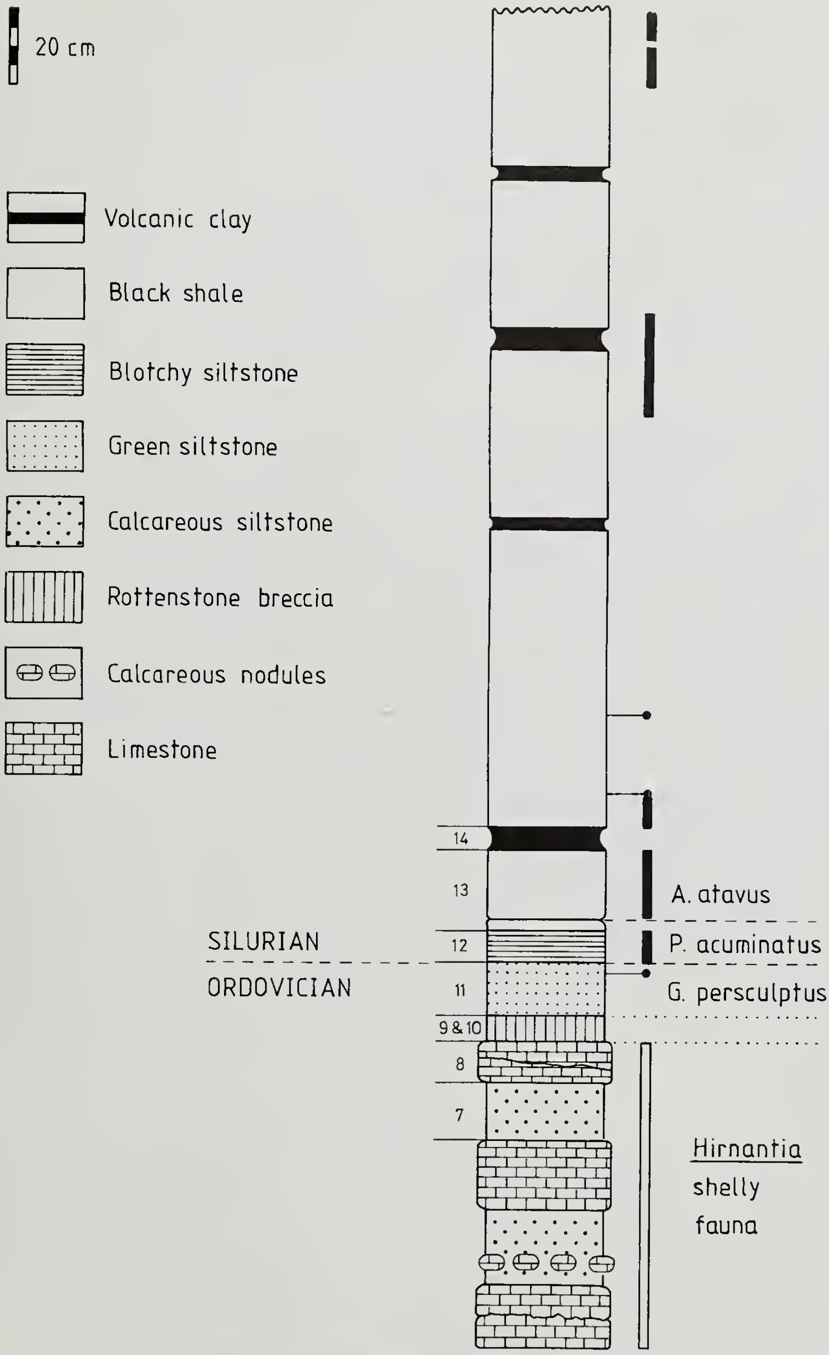

Fig. 2 The lithological log obtained for the trench cutting across the quarry track of Fig. 1, showing the position of the Ordovician–Silurian boundary. Numbers of lithological units discussed in the text are as in Wright (1985). The black spots and bars to the right of the log respectively indicate specific horizons or bulk samples yielding graptolite assemblages.

together with dalmanellid, lingulide, orthid, sowerbyellid, strophomenide and triplesiid fragments. In addition to pelmatozoan and bryozoan debris, trilobite, bivalve and hyolith fragments are also recorded. This is a *Hirnantia* shelly fauna, and differs principally from Temple's fauna in the apparent complete absence of craniids which accounted for more than two-fifths of the entire brachiopod assemblages from the weathered limestones (Temple 1968: 9).

Overlying these beds is a thin (7 cm) rottenstone breccia (units 9 and 10). This is the only indication of a break in the sequence and is interpreted as the result of minor tectonic movement along the surface of lithological change from the underlying carbonate dominated sequence to the overlying fine-grained and non-carbonate clastics. Angular clasts of both fossiliferous shelly Hirnantian and unfossiliferous greenish siltstone (matching the unit 11 sediment) occur in the breccia. No diagnostic shelly fossils have been located in the sequence above unit 10. The first graptolites recovered by Rickards are from a horizon 2 cm below the top of unit 11 and indicate the *Glyptograptus persculptus* Biozone. This fauna comprises *Climacograptus* cf. *miserabilis*, *Climacograptus* ? *medius*, *Glyptograptus* sp. and *Glyptograptus* ex gr. *persculptus*.

Unit 12 is an 8 cm unit of silt with a blotchy and mottled appearance produced by an increase in the proportion of dark muddy silt that first appears in the greenish siltstones of unit 11 (Wright 1985: 269). Despite clear evidence of bioturbation, a small graptolite fauna from a bulk sample of the unit contained specimens of *Climacograptus normalis* and cf. *Parakidograptus acuminatus*, and indicates the presence of the *Parakidograptus acuminatus* Biozone. The Ordovician–Silurian boundary at Keisley is accordingly placed at the base of lithological unit 12. This seems to be the most logical horizon although, as noted previously (Wright 1985), there is clearly a little uncertainty regarding the precise appearance of the *acuminatus* fauna within a bulk sample taken from the 8 cm unit.

Unit 13 lithologically shows a further stage in the transition from the greenish siltstones at the base of unit 11 towards the micaceous black silty shales of the overlying sequence. In this unit the dark material is dominant, although some horizons and patches of the greenish-grey siltstones still occur; concomitantly with the overall colour change, bioturbation disappears. At 2·5 cm above the base of this unit, the first of a series of bentonite clays occurs. A fauna collected from a bulk sample above this clay (Fig. 2) yielded *Climacograptus medius*, *Climacograptus* cf. *normalis* and *Dimorphograptus* sp. This assemblage is identified by Rickards as a post-*acuminatus* one, i.e. from the base of the *atavus* Zone. Accordingly the *acuminatus–atavus* boundary is placed at the thin bentonite band, which is a useful marker that may assist with correlation elsewhere, although the appearance of *atavus* Biozone bentonites in the Keisley trench is a major surprise in the northern England context (Wright 1985). The increasingly rich graptolite faunas from the overlying sequence in the trench all belong to the *atavus* Biozone.

Thus although the *persculptus* and *acuminatus* Biozones occur in thin lithological units at Keisley, both do occur and accordingly enable the Ordovician–Silurian boundary to be precisely located.

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